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A Review of Evidence for High Lift Coefficients
on Propeller and Rotor Blades Under Static Thrust Conditions with
Some New Experimental Results

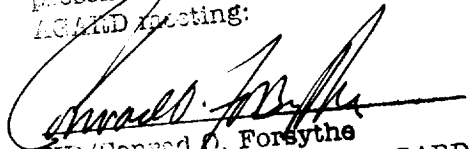
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ABSTRACT/BINAT PAPER
appears suitable for
presentation at
AGARD meeting:

Abstract


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Interest has increased recently in the thrust-producing capability of rotors at very high collective pitch angles. An early reference (Himmelskamp's work) can be found in Schlichting (Ref. 1). Benoit and Bousquet, in a 1990 Stockholm conference paper, noted this behaviour in rotors and offered alternative models for section lift characteristics to explain it. The same phenomenon was coincidentally noted and used in a propeller code by Talbot [Ref. 2] resulting in very good correlation with static thrust data.

The proposed paper will present experimental data demonstrating the pronounced persistence of thrust for propellers at increasing collective pitch angles. Comparisons with blade element/momentum theory will be made. These results are expected to point to the need to define (ultimately to explain) aerodynamic lift and drag behaviour in a rotating environment.

Experimental measurements made by Tung and Branum of the U.S. Army Aeroflightdynamics Directorate at the Ames Research Center have shown [Ref. 3] that locally measured normal force coefficients along the span of a highly twisted rotor blade continue to increase at high values of collective pitch. In some cases these coefficients exceed expected values for the same type of airfoil tested under two

dimensional conditions (Figure 1; data from Tung and Branum). To date no one to the authors' knowledge has defined the variation of C_n with pitch for very high angles (to 45 deg) in a rotating environment and for a blade of reasonably high aspect ratio.; however, total propeller thrust measurements support the idea that stalling does not occur in the same way as on a wing. This paper will present experimental data in the form of surface pressure distributions as well as flow visualization (microtufts) to explore the aerodynamic behavior of the rotating airfoil at high values of blade incidence.

The rotor used by Tung and Branum was modeled using blade element theory for each of the two lift curves shown in Fig. 2. A comparison of the theoretical prediction with the data obtained is shown in Fig. 3. As the data illustrates, use of the conventional two-dimensional lift curve significantly underpredicts the rotor thrust, while the continuously increasing lift curve yields results much closer to the experimental data. This is not interpreted as proof of high lift coefficients, but rather as sufficient evidence to warrant a much closer look at the details of the aerodynamics of the rotating wing at high pitch.

This paper reviews experimental evidence and infers some high lift coefficient behaviour from it. Comparisons between predicted thrust, utilizing modified airfoil characteristics and a blade element model, and measured thrust for both rotors and propellers that cover the extremes of collective pitch are shown and discussed as in Fig. 4.

A new series of experiments is currently underway to directly compare the rotating and nonrotating normal force behaviour on a single propeller blade station as a function of blade incidence. The objective is to compare maximum normal force values, surface pressure distributions and flow field geometry directly under rotating and nonrotating conditions, using the rotor of Tung and Branum. A single blade was mounted as a highly twisted wing in the U.S. Army Aeroflightdynamics Directorate 7x10 wind tunnel at Ames Research Center, Moffett Field, CA. in August 1993. Nonrotating test data has been obtained and reduced (Fig 5). A new series of rotating blade tests is scheduled for July of 1994 in the U.S. Army's anechoic chamber. The purpose of these tests is to measure surface pressure distributions, thrust, and power required for the propeller at increasing values of collective pitch until maximum lift is identified. Comparisons with the earlier data indicate that within the range covered

by the former tests, C_p vs x/c plots are quite comparable for rotating and nonrotating environments. The primary area of interest, however, is the very high angles at which the theoretical thrust drops off, while the experimental thrust continues to increase.

The usefulness of this research has application to a more precise prediction of the performance limits of tail rotors. It is necessary to know maximum thrust for handling qualities purposes and to know torque and thrust accurately for loads and power during design. Additionally, rotorcraft simulation mathematical models using blade element models currently use two-dimensional test data for airfoil characteristics which would give improper results at the highest thrust levels. An understanding of the phenomenon may lead to improved rotor designs.

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References

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p 694

[2.] Talbot, Peter D. "Propeller Performance Program Using Blade Element
Momentum Theory." NASA Ames Research Center Rotorcraft Technology
Branch Working Paper, September 1989

[3.] Tung, C. and Branum, L. "Model Tiltrotor Hover Performance and Surface Pressure Measurement ." AHS Forum, May 1990.

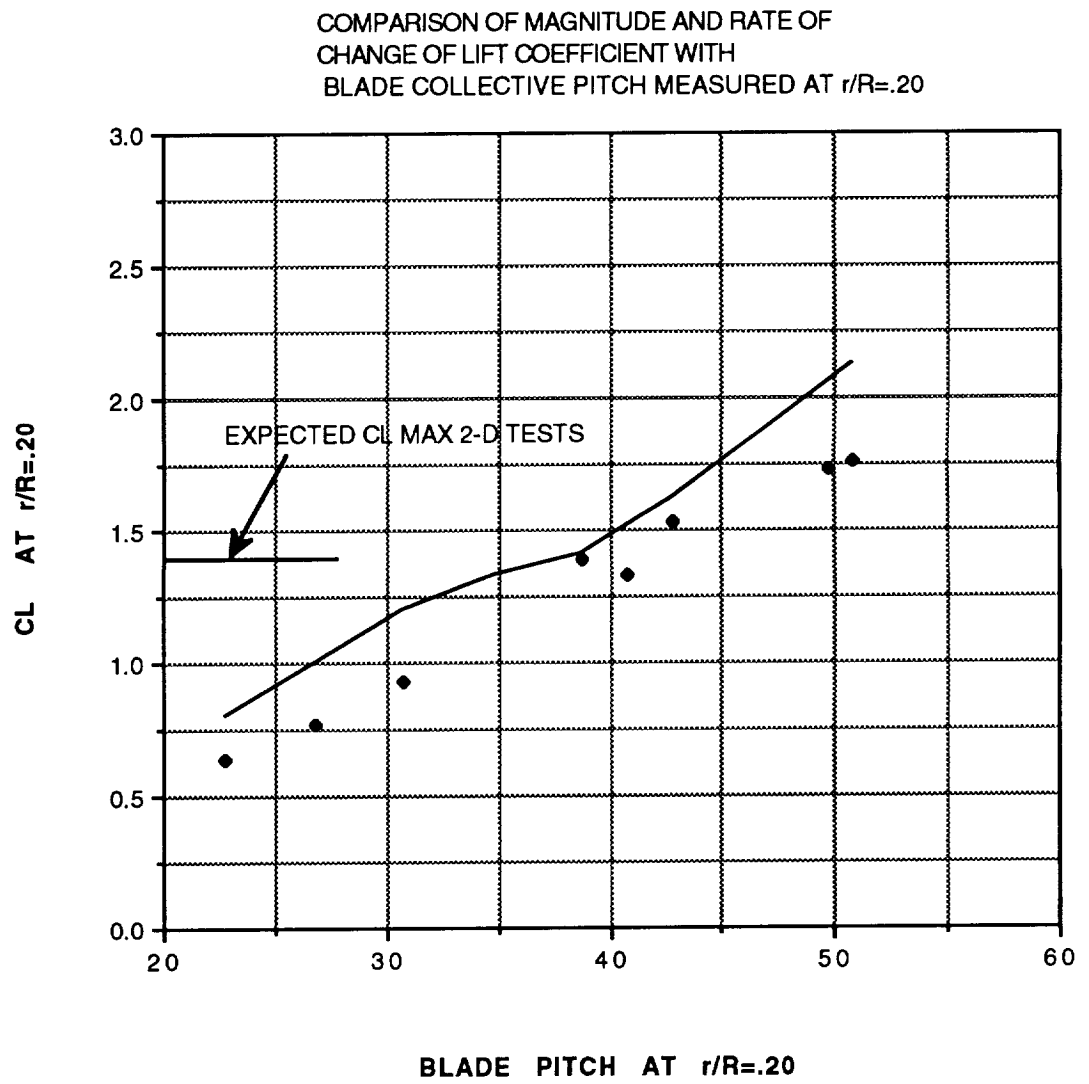


Figure 1. Inboard Lift Coefficients on a Propeller (from Tung and Branum) : $r/R=.20$,
 $t/c=.40$

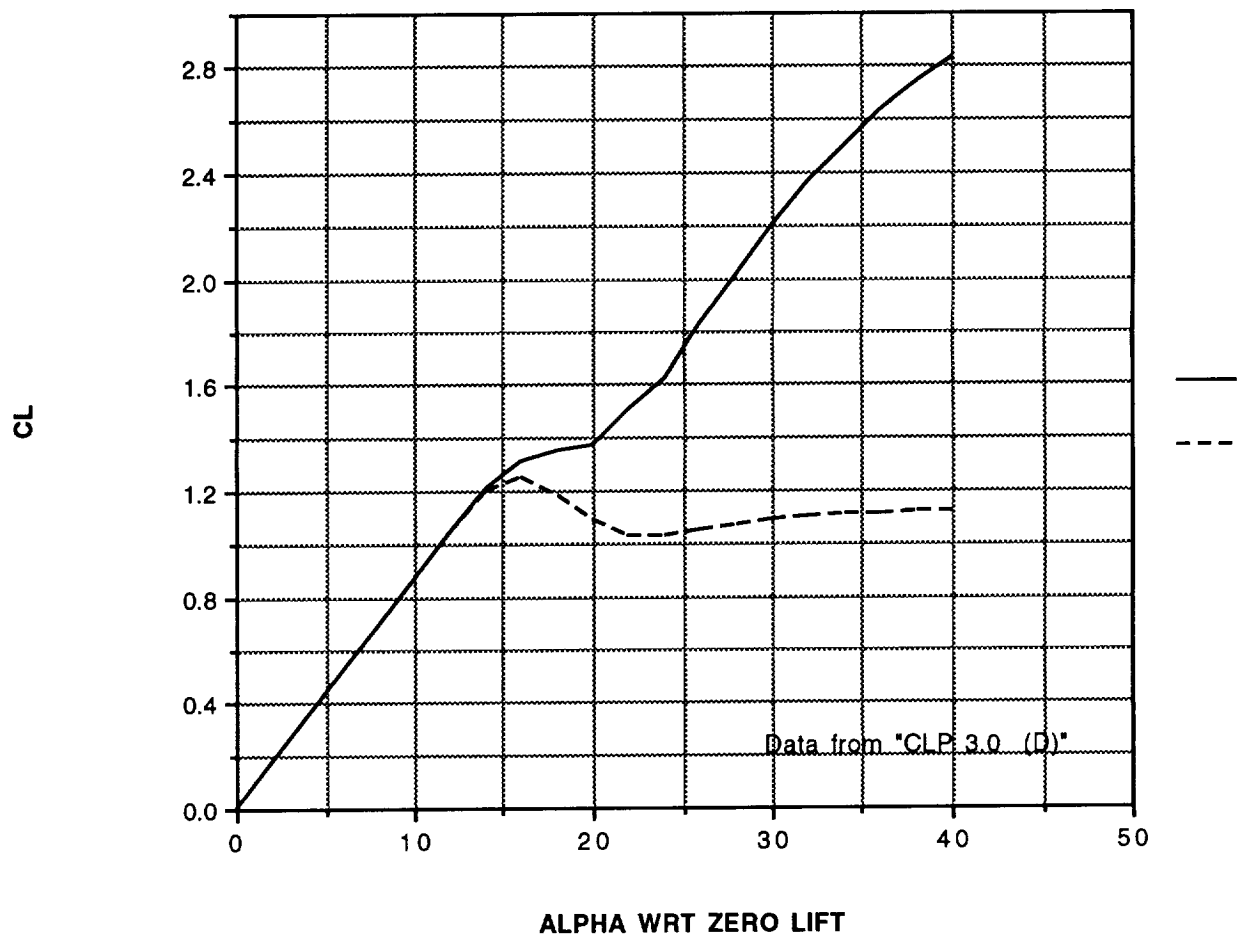


Figure 2. Assumed Models for CL vs Alpha

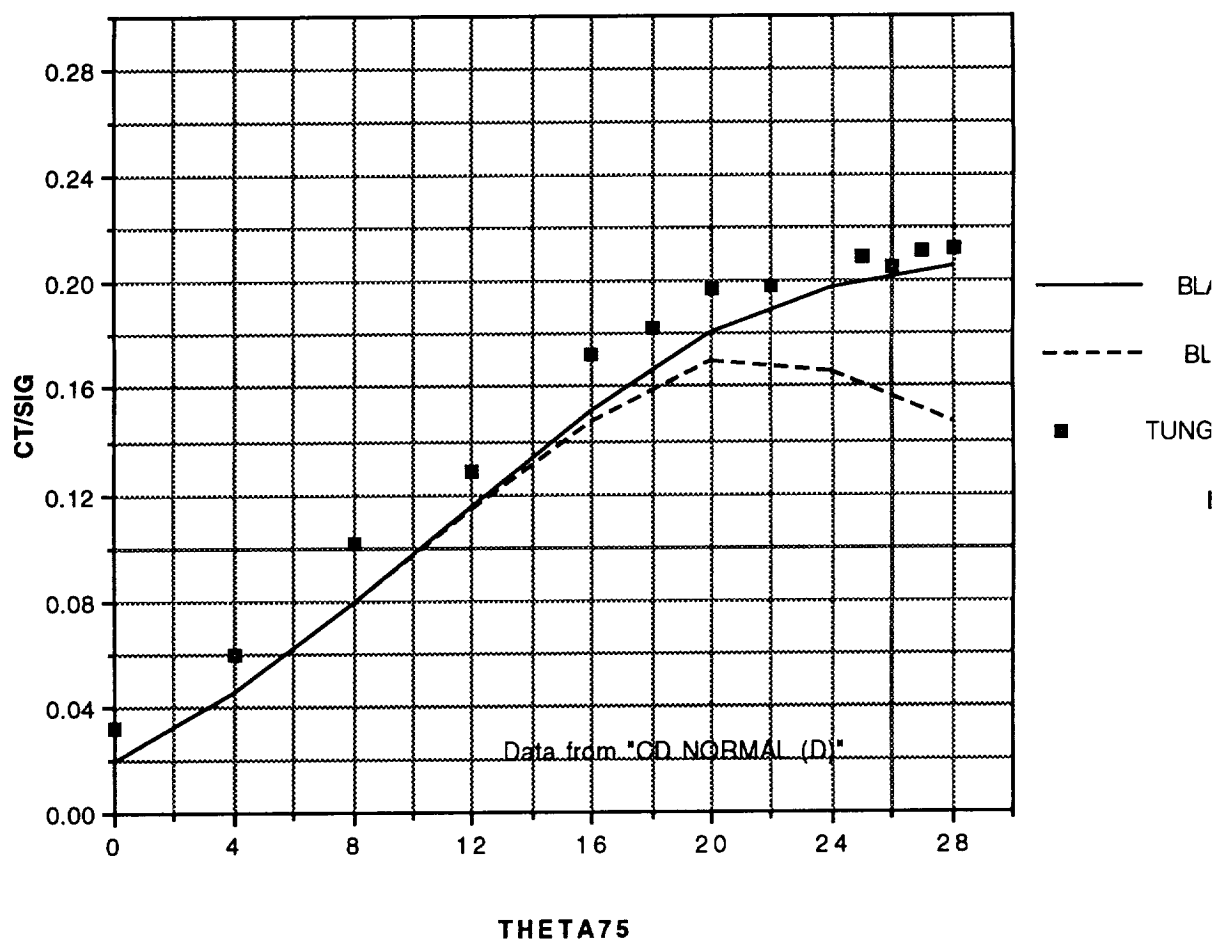


Figure 3. Results of Applying Hypothetical Lift Curves in Blade Element Model

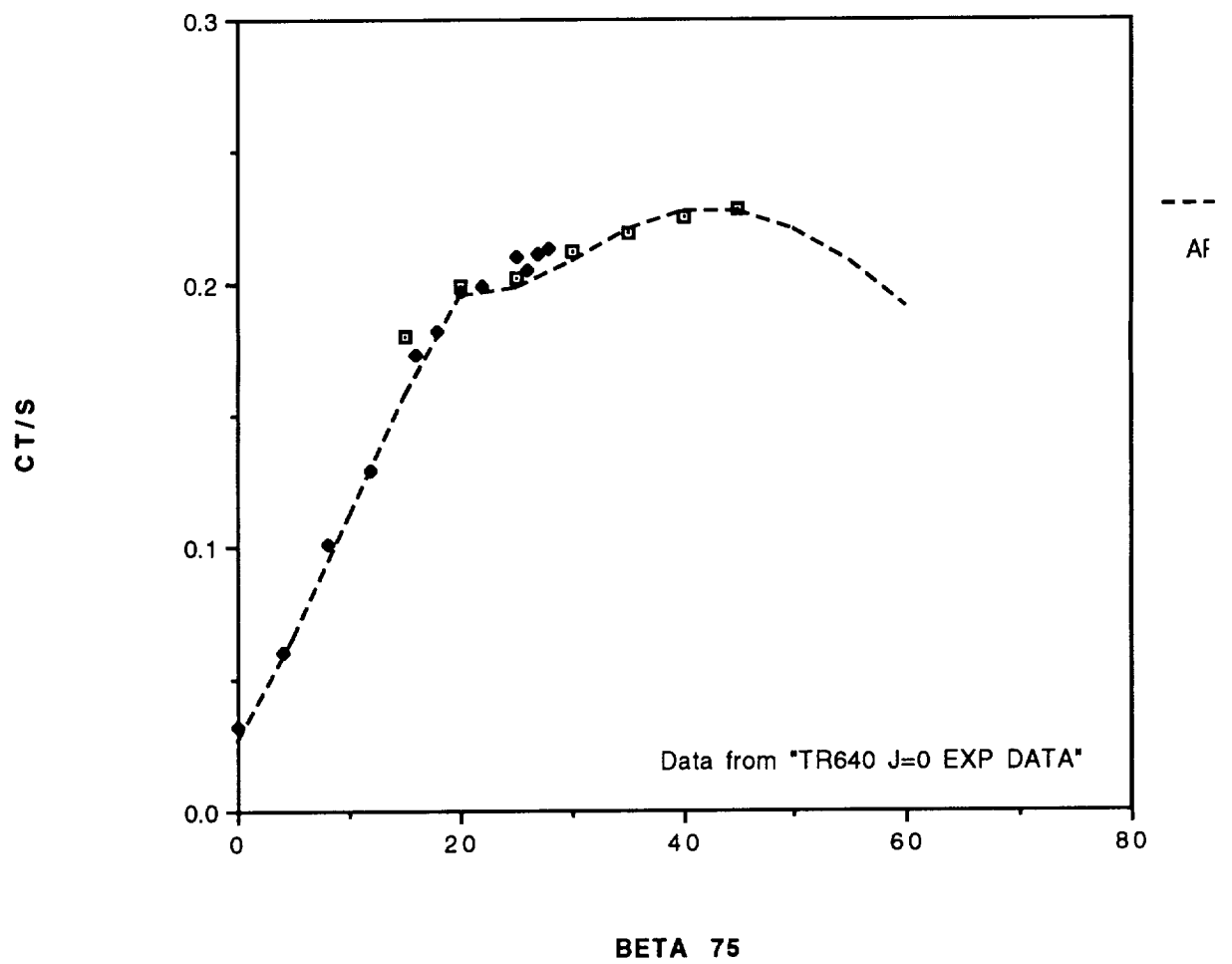


Figure 4. Thrust Behaviour at High Collective Pitch
(NACA propeller data)

**NORMAL FORCE COEFFICIENTS AT
ADJACENT SPANWISE BLADE STATIONS
(NONROTATING PROPELLER BLADE).**

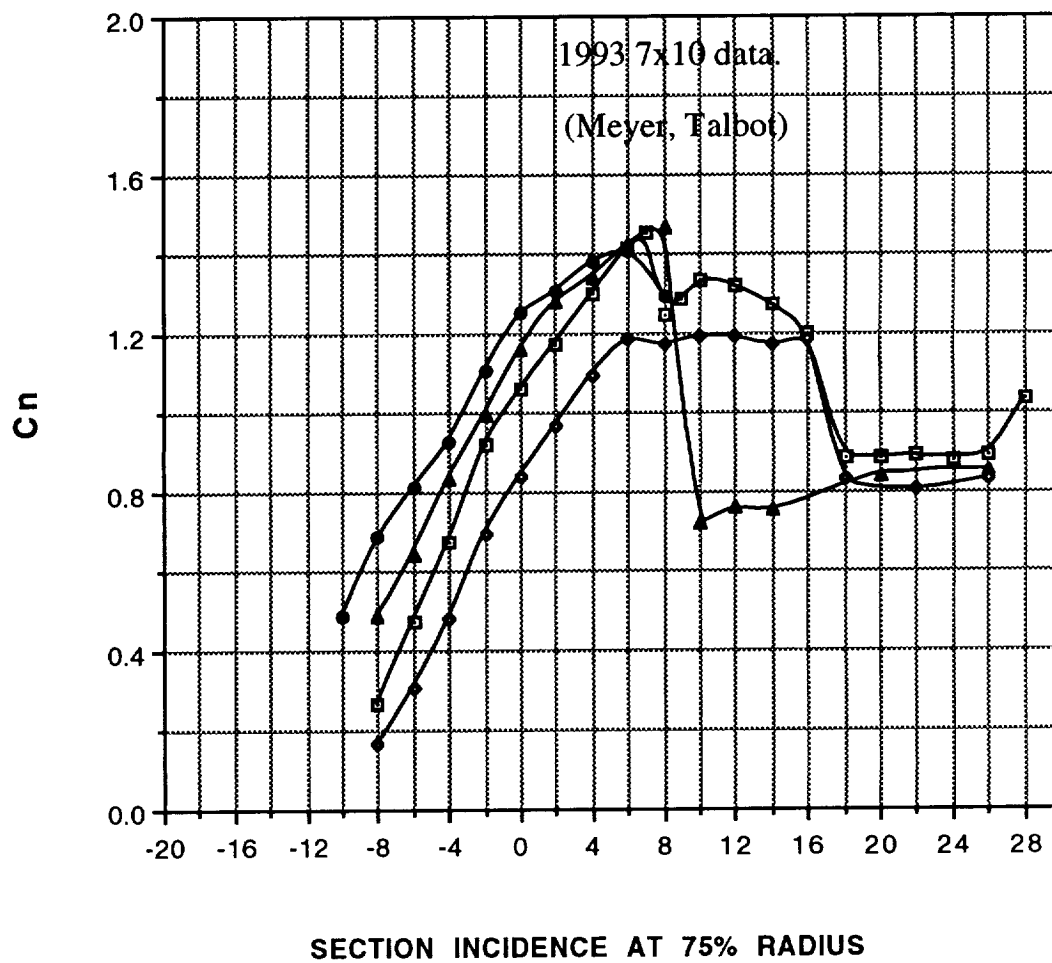


FIG 5.

This material is proposed for presentation in an international aerodynamics forum in the interest of gaining a greater understanding of the phenomena by the entire aerodynamics community. The subject matter and other results have previously been discussed in the open literature, as recently as a paper by Bell Helicopter at an international meeting in San Francisco in January 94. While the material in this paper represents new results, the subject matter and technology level has been presented in open forums for several years including contributions by the European aeronautics community..